N87-17149

OPERATIONAL WAVE FORECASTING WITH SPACEBORNE SAR: PROSPECTS AND PITFALLS

R. C. Beal
Applied Physics Laboratory
The Johns Hopkins University
Laurel, Maryland

I. INTRODUCTION

In April 1965, now more than 20 years ago, a small number of radio scientists and oceanographers congregated at the Woods Hole Oceanographic Institute to consider how the new tools of remote sensing might enhance our understanding of the global ocean environment. Among the techniques considered were radar altimetry, radar scatterometry, and synthetic aperture radar. Of course, at that time, good data sets were scarce, and many of the recommendations were by necessity somewhat speculative in nature. Nevertheless, the complement of active microwave instruments that was identified was very similar to the suite later flown on SEASAT in 1978.

Of particular interest to the topic of ocean wave forecasting is the following quotation from Gifford Ewing, the conference editor. With respect to the value of SAR in monitoring the global wave spectrum, he said:

> "What is needed is the directional energy spectrum of the waves on a two dimensional surface, and for this, the vantage point offered by a satellite is ideal .... It is within the capability of present day radar technology to give a complete description of the sea surface."

That statement was made over 21 years ago. Since then, we have had SEASAT, SIR-A, and SIR-B, all containing high resolution synthetic aperture radars, and all collecting varying "descriptions of the sea surface." The descriptions, however, are only more or less complete, and we are just recently beginning to accumulate the evidence necessary to assess the true value of SAR for obtaining useful estimates of the global directional energy spectrum.

II. THE PROBLEM OF WAVE PREDICTION

Ocean wave prediction over global scales has been a fond hope of oceanographers for several decades. Significant progress was made during and soon after World War II, particularly when the concept of a "wave spectrum" was advanced to describe the statistical properties of the wave field. The idea of an "equilibrium spectrum" gained support from both theoretical and experimental perspectives in the late 1950's, and has served as a framework for departure even up to the present. Moreover, theories of wave growth are now well developed in terms of the source wind field properties, such as fetch and duration, and to some extent even in terms of the "background" wave field. And yet, in the perspective of the global wave prediction problem, there are still several fundamental unanswered questions. These questions center on both the models and on the means for verifying them. For example:

- How often must we measure the wave field in order to predict it?

- Does the background wave field modify wave growth? Are its directional characteristics important?

- Is the directional wave spectrum a sufficiently complete descriptor? How important are wave groups, which may give rise to non-Gaussian statistics?

- How good are the models? How efficiently can they assimilate the data?

- How well can we remotely measure the wave field? How well can we measure it from orbital altitude?

- Can we learn any new physics from the measurements?

- What is the optimum strategy for global wave monitoring? Is it practical? Is its implementation likely to improve wave forecasting?

We do not yet know the answers to these questions, but we are beginning to accumulate a data base which is offering some major contributions toward the solutions.

III. THE SIR-B EXTREME WAVES EXPERIMENT OFF CHILE

From October 8 to 12, 1984, as part of the SIR-B experiment, simultaneous and coincident measurements of the ocean wave directional energy spectrum were made in a NASA P-3 aircraft flying off the southwest coast of Chile. Sea states during the experiment ranged from 1.5 m to 4.5 m, and included fresh seas, decaying swells, and both unimodal and bimodal wave fields. The two primary aircraft instruments were the Surface Contour Radar (SCR; Walsh, 1985) and the Radar Ocean Wave Spectrometer (ROWS; Jackson, 1985), each of which was independently capable of measuring the directional energy spectrum.

Figure 1 illustrates the geometry of the Chile experiment, and Table 1 summarizes the various means of estimating (or predicting) properties of the wave field. The SIR-B was operated through a variety of off-nadir incidence angles, from 40° to 18°. Independent spectral estimates also were made with the airborne optical laser (AOL) and the "AAFE" altimeter, a nadir-looking altimeter yielding estimates of significant wave height. In addition to the aircraft and spacecraft estimates, the U.S. Navy's Global Spectral Ocean Wave Model (GSOWM), which only recently began operating in the Southern Hemisphere, yielded separate estimates of the directional wave spectrum.

IV. EXPERIMENTAL RESULTS

Although a complete set of spectral comparisons is available for each of the last four days of the experiment, only one set will be shown here, that of October 11, 1984. Preliminary comparisons are also reported in Beal et al, 1986a, and more complete comparisons of the entire data set will be forthcoming.

Figure 2 shows the four-way comparison of wave number spectra for each of the aforementioned methods. The spectra from the SCR, ROWS, and GSOWM are all displayed in relative spectral energy density units of m^4. The SAR spectrum is displayed in a similar format simply by assuming that the image Fourier transform, after appropriate spectral smoothing and correcting for a stationary point source response function, Beal et al, 1983; 1986b, is closely related to the ocean wave slope spectrum. With this assumption, the displayed spectrum is simply the slope spectrum times $1/k^2$, where k = wavenumber.

All the spectral estimates are similar in their gross features, with both the ROWS and SAR exhibiting 180° ambiguity. There are, however, slight differences, particularly in the high wavenumber tails of the spectrum, which are not yet satisfactorily resolved. Nevertheless, all instruments agree well in wavenumber and direction, as well as in spectral and angular width of the dominant system. On the other hand, the GSOWM estimate appears rotated clockwise by nearly 30°. This angular bias of GSOWM persists throughout the entire data set, and clearly shows the potential value of actual wave measurements as an update and correction for global models.

On other days, the agreement is not always so impressive. In particular, azimuth traveling waves in low sea states (i.e., wave systems having large dominant wavenumber) are severely attenuated and sometimes obliterated. This azimuth wavenumber distortion results from the Doppler nature of the SAR, and is a particular problem for high altitude (>300 km) orbiting platforms. For this reason, it now appears that global spectral estimates may best be obtained from a low altitude satellite employing both a SAR and a ROWS. Such a design has been described at a recent symposium on "Measuring Ocean Waves from Space," held at the Applied Physics Laboratory. A more complete description of the concept, dubbed "Spectrasat," can be found in the Symposium Proceedings, to appear in the first half of 1987.

SUMMARY

Measurements collected in the SIR-B Extreme Waves Experiment confirm the ability of SAR to yield useful estimates of wave directional energy spectra over global scales, at least for shuttle altitudes. However, azimuth fall-off effects tend to become severe for wavelengths shorter than about 100 m in most sea states. Moreover, the azimuth fall-off problem becomes increasingly severe as the platform altitude increases beyond 300 km. The most viable solution to the global wave measurements problem may be a low altitude spacecraft containing a combination of both the SAR and the ROWS. Such a combination could have a synergy which would yield global spectral estimates superior to those of either instrument singly employed.

ACKNOWLEDGMENTS

This work is a portion of the SIR-B Extreme Waves Team effort. Members of the team are: F. M. Monaldo, D. G. Tilley, D. E. Irvine, E. J. Walsh, F. C. Jackson, D. W. Hancock III, D. E. Hines, R. N. Swift, F. I. Gonzalez, D. R. Lyzenga, and L. F. Zambresky. Many others also contributed. This work was supported by NASA and the Office of Naval Research.

REFERENCES

Beal, R. C., F. M. Monaldo, D. G. Tilley, D. E. Irvine, E. J. Walsh, F. C. Jackson, D. W. Hancock III, D. E. Hines, R. N. Swift, F. I. Gonzalez, D. R. Lyzenga, and L. F. Zambresky, "A Comparison of SIR-B Directional Ocean Wave Spectra with Aircraft Scanning Radar Spectra and Global Spectral Ocean Wave Model Predictions," Science (in press), 1986a.

Beal, R. C., F. M. Monaldo, and D. G. Tilley, "Large and Small Scale Spatial Evolution of Digitally Processed Ocean Wave Spectra from the SEASAT Synthetic Aperture Radar," J. Geophys. Res., 88, 1761-1778, 1983.

Beal, R. C., T. W. Gerling, D. E. Irvine, F. M. Monaldo, and D. G. Tilley, "Spatial Variations of Ocean Wave Directional Spectra from the SEASAT Synthetic Aperture Radar," J. Geophys. Res., Vol. 91, No. C2, 2433-2449, February 15, 1986.

Jackson, F. C., W. T. Walton, and C. Y. Peng, "A Comparison of In Situ and Airborne Radar Observations of Ocean Wave Directionality," J. Geophys. Res., 90, 1005-1918, 1985.

Walsh, E. J., D. W. Hancock III, D. E. Hines, R. N. Swift, and J. F. Scott, "Directional Wave Spectra Measured with the Surface Contour Radar," J. Phys. Oceanogr., 15, 566-592, 1985.

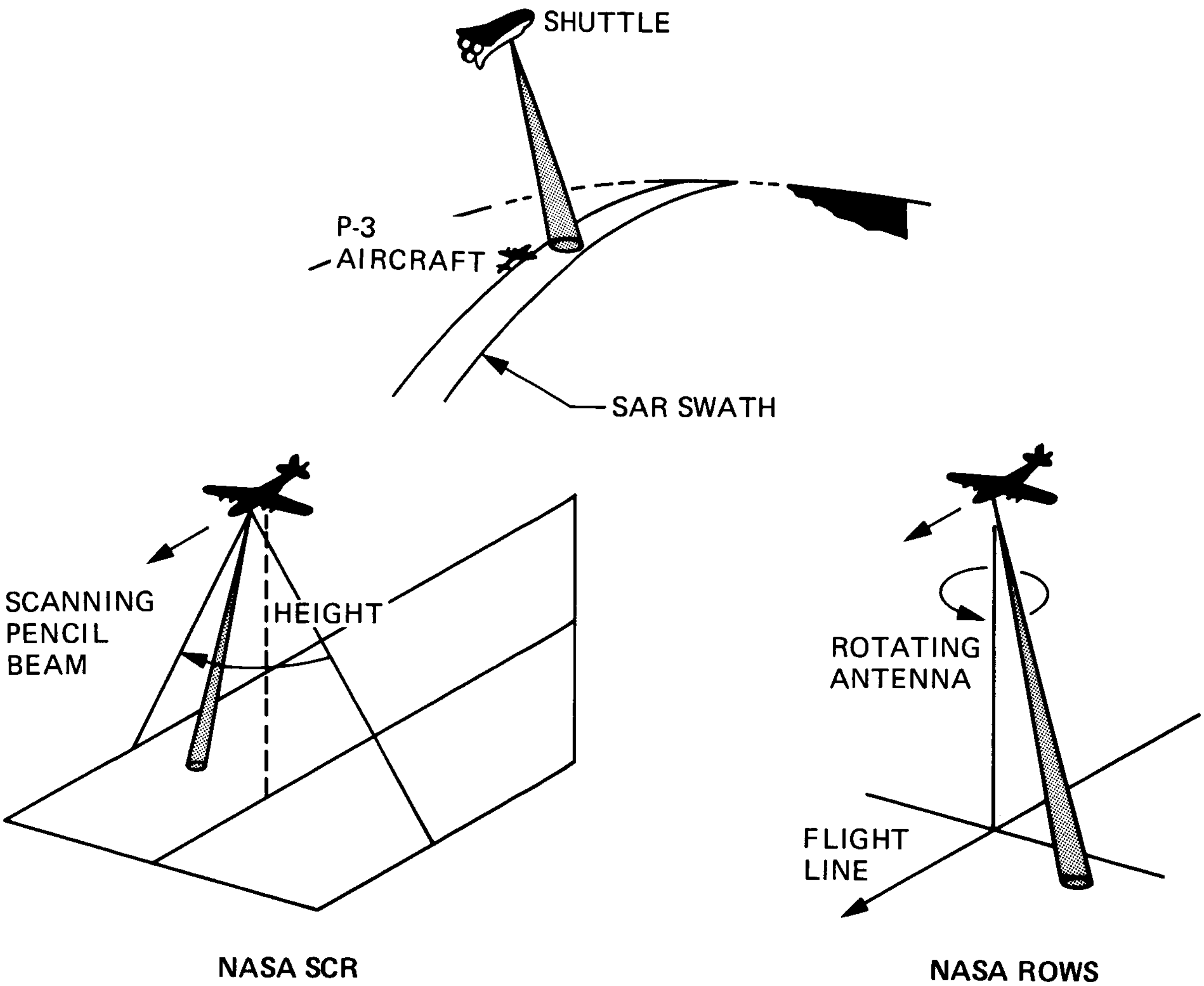

Figure 1. SIR-B Chile experiment

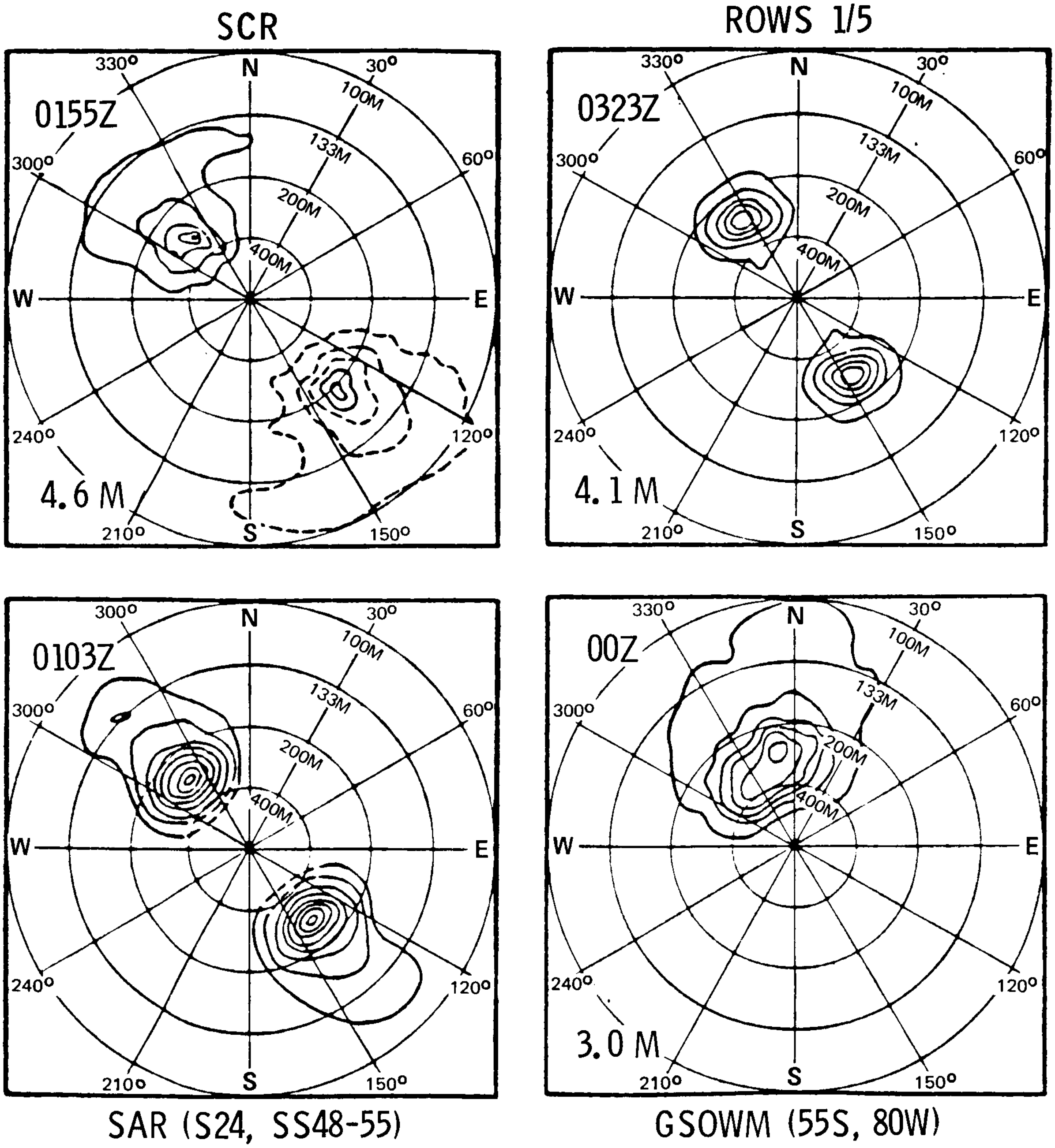

Figure 2. SIR-B spectral comparisons, Chilean coast, October 11, 1984; data take 91.50 (flight #4)

Table 1. Chile data set summary

Date	SIR-B	Wave estimates					
		NASA P-3 aircraft					GSOWM
		FLT #	SCR	ROWS	AOL	AAFE	
8 Oct	40°	1	X	X	√	√	√
9 Oct	35°	2	√	√	√	√	√
10 Oct	30°	3	√	√	X	(√)	√
11 Oct	25°	4	√	√	√	√	√
12 Oct	18°	5	√	√	√	√	√

Data quality: √good (√) marginal X absent